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Memoirs of the Department of Agriculture in India

STUDIES IN INDIAN OIL SEEDS

No. 1. SAFFLOWER AND MUSTARD

BY

ALBERT HOWARD, C.I.E., M.A
Imperial Economic Botanist
Pusa

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Second Imperial Economic Botanist
Pusa

AND

ABDUR RAHMAN KHAN
Second Assistant to the Imperial Economic Botanist

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INDIAN SAFFLOWER.

I. INTRODUCTION.

Safflower (*Carthamus tinctorius*, L.) is widely cultivated in India, both as an oil-seed and for the reddish dye in the flowers (carthamin). Watt, in the *Commercial Products of India*, states that there are two main "conditions," one grown for its flowers, the safflower dye of commerce, the other for its oil-yielding seeds, the *kusum* oil of trade. The former is said to be fairly extensively cultivated in Bengal, the United Provinces, the Central Provinces and Bombay. The best dye is said to come from the Dacca Division of Bengal and the best *kusum* oil from the Deccan. Open sandy soils suit the crop, which is generally grown mixed with gram, barley or wheat. On this account, the area under safflower is not recorded separately in the statistics of Indian crops. The export of safflower dye is small and, in 1912-13, amounted only to 4,250 cwt. which for the most part was sent from Calcutta to the Straits Settlements and Hongkong. In addition to the oil, the dye in the flowers is largely used by the people in India and, in spite of the competition of aniline dyes, still maintains its position. The rose-coloured turbans worn by the Marwari traders of Rajputana are dyed with safflower. Duthie and Fuller, in *Field and Garden Crops of the North-West Provinces and*

Oudh, state that the great demand for the dye from Rajputana accounts for the large area under safflower in the Meerut Division, the dye finding its way to the consumers through the market at Delhi.

The dye occurs in the florets which, after the setting of the seeds, are collected as frequently as possible. Two colouring matters occur—a yellow pigment soluble in water and safflower red (carthamin) insoluble in water but soluble in alkalis. After the collection of the florets, the crop is allowed to ripen its seeds from which *kusum* oil is extracted. This is used locally, both for culinary purposes and also as an adulterant of *ghi* and of *til* oil.

Since 1908, the safflower crop has received some attention at Pusa and twenty-four different types, breeding true, have been selected from seed obtained from Bihar, Bombay, Sind and the United Provinces. These types cover a wide range of forms both as regards habit, foliage and the distribution of the red colouring matter in the flowers.

II. BIOLOGY OF THE FLOWER.

Flowering.

The capitula are borne at the ends of the branches well beyond the large leaves. Each main branch ends in a capitulum, the flowers of which begin to open before those of the inflorescences on the secondary branches. As soon as these secondary branches have completed their growth in length and have carried their single capitula to the flowering region, flowers begin to appear in these inflorescences. Flowering begins in the inflorescence which terminates the main axis of the plant, followed by the first formed capitula of the main branches. The secondary and tertiary branches continue the process in regular order. The total flowering period varies from three to four weeks and usually takes about twenty-five days.

Pollination.

The florets at the margin of the capitulum open first and flowering proceeds centripetally, the whole taking about four days. They usually begin to open in the morning and the process goes on till mid-day. A few, however, open in the afternoon. They remain open one or two days before fading. In the bud stage, the style elongates and the stigma usually emerges from the anther tube before the pollen is liberated. Soon after the extrusion of the stigma, the corolla opens and anthesis takes place while the hairy portion of the style is still within the tube. The continued growth in length of the style enables the numerous hairs to sweep a large amount of

the pollen from the tube into the open air. An examination of the florets at this period shows the stigma in the great majority of cases quite free from pollen, but with numerous grains adhering all round the hairy region of the style. In some cases, however, anthesis takes place before the extrusion of the stigma thus rendering self-pollination possible. Bees visit the capitula in large numbers in the mornings and pay particular attention to the newly opened florets in which anthesis has already taken place. They clear away the pollen adhering to the style and to accomplish this have to stroke it in the direction of the stigmatic surface. In this way, a few pollen grains are carried to the stigma and pollination takes place. By this method of transference of pollen from the anther to the stigma, both self- and cross-pollination are bound to take place as the bees work daily on all the types of plants with open flowers. Besides this method of pollination, it will be evident that the slightest movement of the capitulum by wind or by the operations of the bees might easily carry pollen from one flower to its neighbour and geitonogamy is thus easily possible. Both self- and cross-pollination are therefore likely to take place in this crop. A consideration of all the facts points to the probability that selfing is much commoner than crossing.

Very little setting takes place under parchment paper bags as compared with the results observed in the case of free-flowering inflorescences. On the other hand, when the plants are enclosed, either in muslin or mosquito nets, this difference largely disappears as will be seen from the observations summarized in Table I.

TABLE I.

Setting of protected and free-flowering plants.

No. of culture	Date when first flower appeared	AVERAGE NUMBER OF SEEDS PER HEAD				
		1911		1914		
		Bagged	Free-flowering	Bagged	Netted	Free-flowering
1	2-3-14	9	41	9	25	22
4	25-2-14	19	51	19	35	43
5	16-2-14	9	27	1	27	25
6	14-2-14	3	34	12	24	33
36	23-2-14	5	50	18	48	48
38	23-2-14	7	39	21	36	28
39	20-2-14	1	30	1	36	38

TABLE I.—*contd.*

Setting of protected and free-flowering plants.

No. of culture	Date when first flower appeared	AVERAGE NUMBER OF SEEDS PER HEAD				
		1911		1914		
		Bagged	Free-flowering	Bagged	Netted	Free-flowering
2	23-2-14	15	33	8	27	30
3	23-2-14	10	46	15	44	40
12	23-2-14	6	57	7	37	35
13	20-2-14	6	24	26	29	26
14	2-3-14	16	42	3	26	22
15	25-2-14	7	41	14	54	43
30	20-2-14	14	65	16	28	39
27	27-2-14	9	54	13	50	49
31	23-2-14	9	35	5	23	23
32	23-2-14	26	58	5	28	40
34	20-2-14	15	48	15	38	41
42	25-2-14	15	68	14	42	45
17	3-3-14	9	54	18	38	50
8	9-3-14	21	48	3	31	39
10	14-3-14	7	54	5	36	38
23	2-3-14	10	46	10	44	41
24	10-3-14	6	54	13	40	52
20	4-3-14	18	55	15	51	44
	AVERAGE	11	46	12	32	37

These results show that the visits of insects like bees are not necessary for pollination provided that air movement and the natural humidity are not interfered with. Under parchment paper bags, there is necessarily little air movement and the chances are small of the stigma of one flower coming in contact with the pollen covered style of its neighbour at the proper moment. Further, the higher humidity and possibly the higher temperature inside the bag would both tend to reduce the amount of pollination. Under large nets, which cover almost the whole flowering portion of the plant, there is little difference between protected and unprotected flowers as regards air movement, humidity and temperature and under such circumstances geitonogamy is readily possible and is observed to take place.

In order to determine the effect of increased humidity on pollination, a comparison was made in 1915 between setting in lamp chimneys, closed below and partially open above, and in the free air. The results are set out in Table II.

TABLE II.

The effect of increased humidity on setting.

Culture	NUMBER OF SEEDS IN EACH CAPITULUM	
	In lamp chimneys	In free air
1	0	21
	0	11
	1	31
	0	27
25	0	48
	1	40
	0	52
	6	50
2	3	21
	0	43
	0	34
8	0	52
	0	37
	0	23
	1	39
15	13	63
	13	55
TOTAL	38	647
AVERAGE	2·2	38

The inhibiting effect of the moist confined air is very great and, at first sight, the result would be put down entirely to the effect of the increased humidity. It is possible, however, that temperature plays a part and that pollen grains will not germinate readily in moist, hot air.

It is found that while the number of seeds set in free-flowering capitula on the same plant at any particular period is to a great extent uniform, nevertheless there is very great variation in the number set under parchment bags. No setting at all takes place in many cases under bag as will be seen from the results set out in Table III. In some cases, such as cultures 5 and 8, the influence of the bag is far less deleterious than in others. The cause of this great variation has not been investigated.

TABLE III.

Setting in individual heads on the same plant.

No.	Kind of head	Number of head											Total no. of Seeds		
		1	2	3	4	5	6	7	8	9	10	11	Bagged	Free-flowering	Average
1	Bagged	1	17	14	0	0	0	0	0	0	0		3		0·3
	Free-flowering	34	31	37										105	35
2	Bagged	2	8	10	1	6	16	12	9	0	0	0	63		5
	Free-flowering	46	42	34	40	26								188	38
3	Bagged	15	9	15	12	5	19	1	18	2.	1	15	131		11
	Free-flowering	34	35	30	29	40	33							201	34
4	Bagged	12	5	3	12	12	10	0	0	0	0		54		5
	Free-flowering	34	48	39	34	47								202	40
5	Bagged	22	23	12	27	28	8	23	26	0			169		19
	Free-flowering	37	35	37	35	35								179	35
6	Bagged	13	22	23	10	4	22	3	2	0	0	0	99		9
	Free-flowering	61	61	70	57	65								317	63
7	Bagged	8	22	4	6	11	2	0	0	0	0		53		5
	Free-flowering	54	45	53	54	52								258	52
8	Bagged	24	8	5	27	28	25	22	0	0	0		139		14
	Free-flowering	61	41	51	44	47								244	49

Average number of seeds per head { Bagged 9. / Free-flowering 43.

The effect of the season on the amount of setting in *rabi* crops at Pusa is particularly well-marked. As a rule, all late varieties set badly and the last formed flowers, even on early kinds, do not produce many seeds. This point was investigated in 1915 in the case of four safflower cultures. The results are given in Table IV from which it is clear that, with one exception, there is a rapid falling off in seed production. So great is this at Pusa that the utmost care has to be taken, in making comparisons, that the observations are made on cultures in similar phases of flowering.

TABLE IV.

The effect of the season on setting.

Type	Average Number of Seeds per Capitulum		
	Early	Intermediate	Late
20	51·7	41·7	29 9
17	19·9	23·3	25·7
13	44·3	39·9	11 9
Dacca	31·0	—	24 7
AVERAGE	36·7	34·9	23·2

A consideration of the development of the flower and of the results of the pollination experiments described above leads to two very definite conclusions. Self-pollination is likely to be the rule in safflower but a fair percentage of natural crossing is also possible. The effect of flowering in confined space, such as in paper bags or in partially closed glass vessels, is to reduce pollination and to interfere very considerably with the number of seeds set. How far temperature is a factor in pollination, under such circumstances, has not been determined but it is probable that it has some influence.

NATURAL CROSS-FERTILIZATION.

The extent to which natural crossing has produced heterozygotes in safflower in Bihar has been referred to in a previous paper.[1] Out of 76 single plants selected, only two bred true in all respects. Variation occurred in many directions, namely, in the colour of the flowers, in the habit of the plants, whether tall or spreading, in the degree of hairiness and of spinosity of the bracts of the inflorescence and also as regards the characters of the leaves.

The colour of the florets in the bud stage varies from whitish through various shades of yellow to reddish. These colours are best seen just as the

[1] *Mem. of the Dept. of Agr. in India (Botanical Series)*, vol. III, no. 6, 1910.

buds are ready to open. When fully opened, the amount of red colour in the corolla appears to diminish but on fading the redness develops (Plate II). All the whitish and some of the pale yellow flowers bred true but many of the plants with orange florets were heterozygotes and when grown singly gave all stages from yellow to deep orange.

Subsequently, the proportion of heterozygotes was determined in the crop as grown in other parts of India. Out of 22 samples from different places in the Bombay Presidency, 20 proved to be almost pure and these were characterized by a copious development of spines on the leaves and bracts. Three distinct types only were found in these collections from which it appears that the kinds are kept much purer by the people in Bombay than in Bihar. In contrast with these almost pure cultures, the seed received from Ahmedabad and Larkhana (Sind) was very mixed and an examination of the progeny of single plants showed the existence of extensive natural crossing. No less than nine types were finally selected from these two samples. Two samples of seed from Mirpurkhas in Sind were considerably mixed and from these five types were isolated. Two samples from the United Provinces proved to be almost pure and yielded only two types which were characterized by spinose bracts. It will be seen therefore that the safflower crop in India varies greatly in gametic constitution. In some cases, as in the Bombay Presidency, practically pure types are grown whereas, in Bihar and Sind, it is largely made up of heterozygotes.

In order to determine to what extent cross-fertilization takes place at Pusa, when the various types are grown next to next in pure culture, the seed from unprotected flowers of the 1914 crop was sown in the case of four types and the progeny examined. The results are given in Table V from which it will be seen that about sixteen per cent. of the flowers were cross- and the remaining eighty-four per cent. self-fertilized.

TABLE V.

Percentage of crossing at Pusa in 1914.

Type	Total number of plants	Heterozygotes	Percentage of crosses
10	78	9	11·5
11	93	14	15
12	70	19	27
13	80	10	12·5
TOTAL	321	52	AVERAGE 16 5

Since 1910, many of the types of Indian safflower have been raised continuously at Pusa from the seed of protected flowers and all crossing has been prevented. No evidence of loss of vigour from this continuous self-fertilization has been observed. The growth has been robust, the plants have done well and no difficulties have been met with in germinating the seeds. So far, natural crossing does not appear to be essential in maintaining the vigour of the crop.

III. CLASSIFICATION AND DESCRIPTION OF THE TYPES.

Safflower is described in *Field and Garden Crops of the North-West Provinces and Oudh* (I, 51) as follows :—

" A glabrous thistle-like herb with reddish orange flowers. Stems about 2 ft. high, much branched above. Leaves sessile, oblong lanceolate, with serrate aculeate edges or nearly entire. Flowers in large compact heads ; outer involucre bracts leafy, ovate oblong, constricted above the base, entire or spinulose, inner bracts narrower. Florets tubular, hermaphrodite or a few of the marginal ones sterile, tube slender, limb oblong. Anthers sagittate at the base. Achenes $\frac{1}{4}$ in., smooth, obovoid, truncate at the top, obliquely 4-angular, with four projecting ribs."

There are several references in the Indian literature to the occurrence of different forms of safflower. The great contrast between the varieties with spinose and entire bracts is noted by Watt in the *Commercial Products of India* as well as the existence of varieties with yellow as opposed to reddish florets. He states " speaking broadly, the oil-yielding forms are more spinose than the dye-yielding and have usually yellow coloured flowers, the dye forms being orange and even yellow tinted with scarlet." Duthie and Fuller refer to the effect of high cultivation in reducing the spiny character of this crop.

The earlier observers regarded the crop from the point of view of systematic botany and no separation of the types from the mass of heterozygotes was carried out. This has now been done at Pusa in sufficient detail to give an idea of the range in form which exists in Indian safflower.

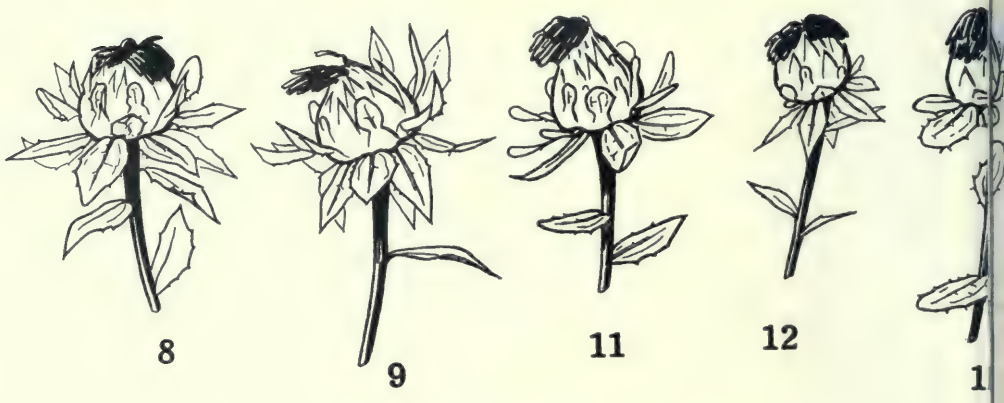
Morphological Characters.

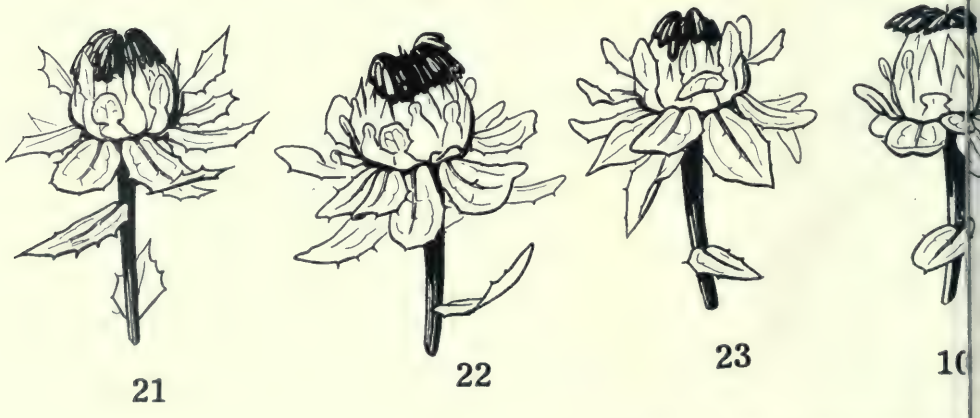
The types of Indian safflower vary greatly particularly as regards the general habit, the leaves, bracts and florets. These facts render the classification of the types and their description a comparatively easy matter.

Habit. The great differences met with in general habit depend on the height, on the angle at which the secondary branches are given off and also on the point on the main stem where branching begins. The range in height of the various types is considerable, the limits in 1914 being 100 and 170 cm. The general angle at which the secondary branches arise from the main stem also shows a wide range from rather dwarf, spreading, well-branched plants to tall forms in which the branches are close to the stem. Approximate measurements of these angles showed that the limits were 15° to 45°. The habit is also influenced by the point on the main stem at which branching begins. The open, spreading forms begin to branch low on the stem, about 5 cm. from the ground, while the tall forms of closer habit do not give off their first laterals below 30 cm. from the base.

Leaves. The large, lower leaves, which are always practically free from spines, vary greatly as regards the margin and the extent of division. The margin usually ranges from wavy to deeply dentate, while in some types the leaves are entire, in others they are divided almost to the midrib. In the late types, the internodes near the base are very short and in these there appears to be a tuft of radical leaves ; in the earlier forms, the internodes are more evenly distributed. In all the types, the leaves diminish in size from below upwards and, in all cases, the upper leaves are more or less spinose. In some types, however, the spines are very small while in others they are highly developed and are both long and numerous. In the massed habit, the differences in leaf-colour between the types become evident. The tone varies from light to a very dark green.

Bracts. In the involucral bracts there is also a great range in form (Plate I). In all the types, the outer bracts are constricted above the base and are always foliaceous and often spinescent. The basal, imbricated portions of the bracts are without spines but these are more or less developed on the foliar part above the constriction. There are great differences among the types in the size, shape, indentation and degree of development of the spines of the foliar portions of the involucral bracts. Those types with spinose upper leaves develop this character in the bracts, while in the almost spineless forms the spines on the bracts are few and short. In some types, the lower imbricated portions of the bracts are covered with soft white hairs, in others, these are nearly absent and the unopened buds look green. The hoary or green appearance of the capitulum is a remarkably constant character and one that has been made use of in classifying the types.





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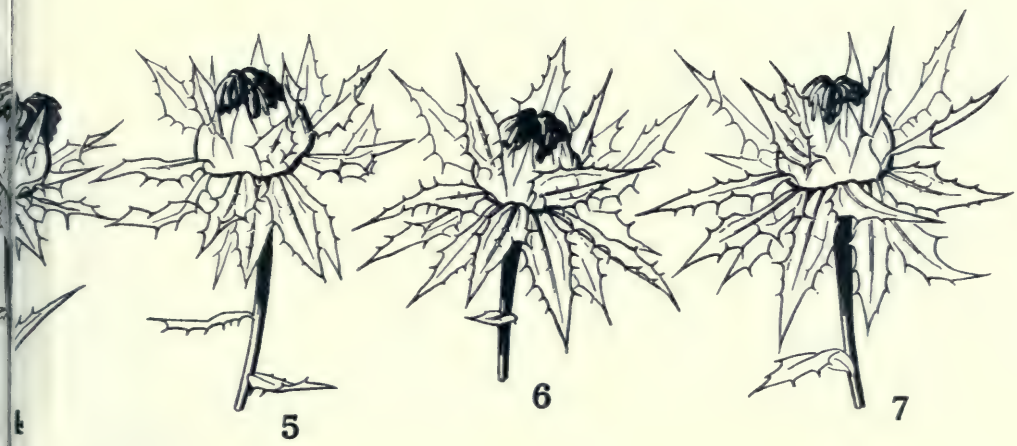

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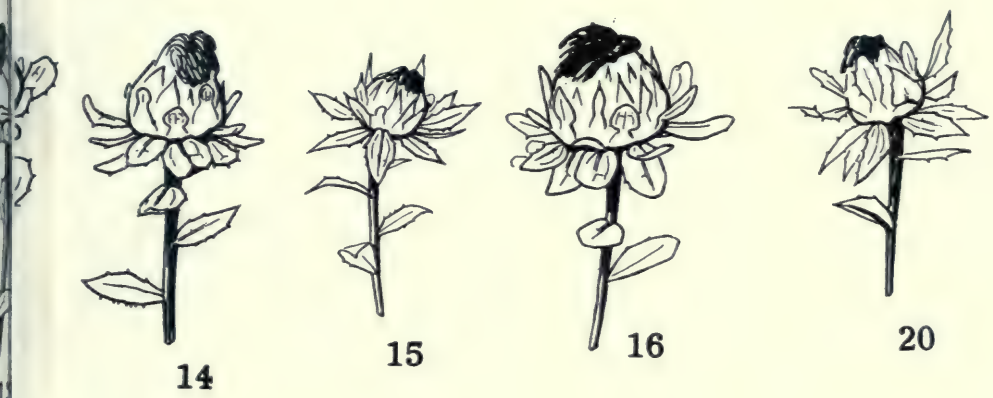

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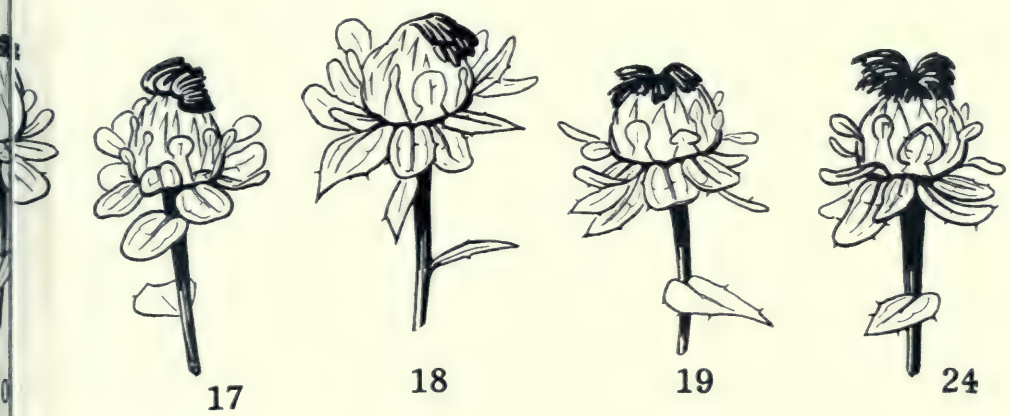

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TYPES OF INDIAN SAFFLOWER.

Florets. The colour of the florets varies from whitish to almost red (Plate II). Between these extremes, yellowish and slightly reddish intermediate types occur. These differences arise from the yellow and red colouring matters in the floret and the degree to which the red colour is developed can be seen both in the unopened buds and in the faded corollas.

Classification of the types.

I. Outer bracts lanceolate, distinctly spinose.

1. Bracts smooth, green.

A. Florets white.

Type 1. Plants tall, erect, leaves dark green, incised. Intermediate as regards time of flowering, very late in ripening.

B. Florets yellow, not turning red on fading.

Type 2. Plants intermediate in height, spreading; leaves light green, incised, bracts long. Intermediate as regards time of flowering.

Type 3. Plants intermediate in height, spreading; leaves dark green, serrate. Very early.

Type 4. Plants short, spreading; leaves very light green, margin dentate; bracts short and narrow. Very early.

C. Florets yellow, turning to red on fading.

a. Flower buds yellow with a red dot on the apex.

Type 5. Plants intermediate in height, somewhat erect; leaves very dark green, dentate. Early.

b. Flower buds yellow with no red dot.

Type 6. Plants intermediate in height, spreading; leaves somewhat light green, serrate. Very early.

Type 7. Very similar to type 6, but the plants are somewhat taller and later and the leaves lighter in colour.

II. Outer bracts ovate to rounded, moderately spinose to spineless.

1. Bracts hairy, whitish.

A. Florets yellow, not turning to red on fading.

a. Flower buds pale yellow.

Type 8. Plants intermediate in height, spreading; leaves dark green, serrate. Early.

b. Flower buds deep yellow.

Type 9. Plants tall, spreading; leaves dark green, almost spineless, serrate. Early.

B. Florets yellow, turning to red on fading.

a. Flower buds deep yellow.

Type 10. Plants tall, very erect with long almost parallel branches; leaves long, dark green, almost spineless, serrate. Late.

Type 11. Plants tall, very erect, branches shorter than in type 10; leaves dark green, spines few, serrate. Early.

Type 12. Plants rather tall, somewhat erect; leaves dark green but lighter than in type 11, serrate; early (later than type 11).

Type 13. Plants tall, erect; leaves long, light green, spines few, incised. Late.

b. Flower buds deep yellow with a trace of red near the apex.

Type 14. Plants tall, erect; leaves long, dark green, spines few, incised. Intermediate in time of maturity.

c. Flower buds deep yellow, reddish near the base.

Type 15. Plants short, spreading; leaves light green, spinose, serrate; bracts spiny. Very early.

Type 16. Plants intermediate in height, spreading; leaves light green, spines few. Intermediate in time of maturity.

d. Flower buds deep red with a yellow apical point.

Type 17. Plants tall, erect with long branches; leaves dark green, nearly spineless, incised. Late.

2. Bracts almost smooth, green, florets yellow turning to red on fading.

A. Flower buds deep yellow.

Type 18. Plants tall, branching above the ground, erect; leaves long, somewhat light green, nearly spineless, deeply incised. Late.

Type 19. Plants tall, erect, branching from the ground; leaves long, dark green, nearly spineless, incised. Very late.

Type 20. Plants short, somewhat spreading, very spinose; leaves small, very light green, serrate. Very early.

B. Flower buds deep yellow with a reddish apex.

Type 21. Plants intermediate in height, somewhat spreading; leaves somewhat light green, incised. Late.

Type 22. Plants tall, somewhat erect, leaves dark green, incised. Early.

C. Flower buds deep yellow with a reddish base.

Type 23. Plants short, spreading; leaves light green, serrate. Intermediate as regards time of maturity.

D. Flower buds deep red with a yellow apical point.

Type 24. Plants tall, erect; leaves long, somewhat light green, incisions few. Late.

Description of the Types.

I. *Outer bracts lanceolate, distinctly spinose.*

Type 1. Intermediate as regards time of flowering but very late in maturing, height 137 cm., habit erect. Leaves 17 × 5 cm., incised, dark green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate, spiny (spines long); inner bracts narrower, 3 × 1 cm. *Florets* white in mature bud or when open, fading to dirty white.

Type 2. Intermediate as regards maturity, height 113 cm., habit spreading. *Leaves* 23 × 8 cm., incised, light green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate with long spines; inner bracts narrower, 3 × 1 cm. *Florets* deep yellow in mature bud, yellow when open, fading to brownish yellow.

Type 3. Very early, height 118 cm., habit spreading. *Leaves* 22 × 6 cm., serrate, dark green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate with long spines; inner bracts narrower, 3 × 1 cm. *Florets* deep yellow in the mature bud, yellow when open, fading to brownish yellow.

Type 4. Very early, height 93 cm., habit spreading. *Leaves* 16 × 4 cm., oblanceolate, dentate, very light green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate with long spines; inner bracts narrower 2·4 × 0·7 cm. *Florets* deep yellow in the mature bud, yellow when open, fading to brownish yellow.

Type 5. Early, height 115 cm., habit spreading. *Leaves* 19 × 6 cm., oblanceolate, dentate, very dark green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate with long spines ; inner bracts narrower. *Florets* deep yellow in the bud with a red dot on the apex, yellow when open, fading to orange red.

Type 6. Very early, height 145 cm., habit spreading. *Leaves* 20 × 6 cm., oblanceolate, serrate, somewhat light green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate with long spines ; inner bracts narrower 3 × 1 cm. *Florets* deep yellow in the mature bud, yellow when open, fading to orange red.

Type 7. Early, height 133 cm., habit spreading. *Leaves* 19 × 5 cm., oblanceolate, dentate, light green. *Inflorescence leaves* lanceolate, spinose-serrate with long spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate with long spines ; inner bracts narrower, 4·4 × 1·1 cm. *Florets* deep yellow in the mature bud, yellow when open, fading to orange red.

II. *Outer bracts ovate to rounded, moderately spinose to spineless.*

Type 8. Early, height 117 cm., habit spreading. *Leaves* 18 × 5 cm., oblanceolate, serrate, dark green. *Inflorescence leaves* lanceolate, spinose with short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical with a few short spines ; inner bracts narrower, felted, 3 × 1 cm *Florets* pale yellow in the mature bud and when open, fading to a brownish tint.

Type 9. Early, height 148 cm., habit spreading. *Leaves* 21 × 5 cm., oblanceolate, serrate, dark green. *Inflorescence leaves* lanceolate, almost entire with a few very short spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate to ovate, with a few short spines ; inner bracts narrower, 2 × 1 cm. *Florets* deep yellow in the mature bud, yellow when open, fading to brownish yellow.

Type 10. Late, height 162 cm., habit erect. *Leaves* 25 × 7 cm., oblanceolate, serrate, dark green. *Inflorescence leaves* lanceolate, entire with occasional short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical, entire with occasional short spines ; inner bracts narrower, felted, 2·5 × 1·6 cm. *Florets* deep yellow in the bud and when open, fading to red.

Type 11. Early, height 145 cm., habit erect. *Leaves* 20 × 5 cm., oblanceolate, dentate, dark green. *Inflorescence leaves* lanceolate, spinose-serrate with short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical, entire with occasional short spines; inner bracts narrower, felted. *Florets* deep yellow in the mature bud, yellow when just open, fading to orange red.

Type 12. Early, height 121 cm., habit somewhat erect. *Leaves* 19 × 5 cm., oblanceolate, serrate, somewhat dark green. *Inflorescence leaves* lanceolate, almost entire with occasional short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical, almost entire with occasional short spines; inner bracts narrower, felted. *Florets* deep yellow in the mature bud, yellow when open, fading to red.

Type 13. Late, height 155 cm., habit somewhat erect. *Leaves* 23 × 5 cm., oblanceolate, incised, light green. *Inflorescence leaves* lanceolate, spinose-serrate with short spines. Outer *involucral bracts* leafy, constricted above the base, obovate to rounded, with occasional short spines; inner bracts narrower, felted. *Florets* deep yellow in the bud, yellow when open, fading to orange red.

Type 14. Intermediate as regards time of maturity, height 152 cm., habit somewhat erect. *Leaves* 22 × 6 cm., oblanceolate, incised, dark green. *Inflorescence leaves* lanceolate, spinose-serrate with short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical to rounded, almost entire with occasional short spines; inner bracts narrower, felted. *Florets* deep yellow in the bud with a trace of red at the apex, yellow when open, fading to red.

Type 15. Early, height 99 cm., habit spreading. *Leaves* 15 × 4 cm., oblanceolate, serrate, light green. *Inflorescence leaves* lanceolate, spinose-serrate with a few short spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate, spinose-serrate with numerous short spines; inner bracts narrower, felted. *Florets* deep yellow with a red ring near the base in the mature bud, yellow when open, fading to red.

Type 16. Intermediate as regards time of maturity, height 111 cm., habit spreading. *Leaves* 18 × 5 cm., oblanceolate, serrate, light green. *Inflorescence leaves* lanceolate, spinose-serrate with a few short spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate to elliptical, almost entire with occasional short spines; inner bracts narrower, felted. *Florets* deep yellow with a red ring near the base in the mature bud, yellow when open, fading to red.

Type 17. Late, height 167 cm., habit erect. *Leaves* 30 × 8 cm., oblanceolate, incised, dark green. *Inflorescence leaves* elliptical, entire, without spines. Outer *involucral bracts* leafy, constricted above the base, elliptical, entire, without spines ; inner bracts narrower, felted. *Florets* deep red with a yellow apical point in the mature bud, orange red with a little yellowness when open, fading to a deep red.

Type 18. Late, height 148 cm., habit erect. *Leaves* 28 × 6 cm., oblanceolate, deeply incised, somewhat light green. *Inflorescence leaves* lanceolate, almost entire with a few short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical to lanceolate, almost entire with occasional short spines ; inner bracts narrower, smooth. *Florets* deep yellow in the mature bud, yellow when open, fading to red.

Type 19. Very late, height 168 cm., habit erect. *Leaves* 30 × 6 cm., oblanceolate, incised, dark green. *Inflorescence leaves* lanceolate with a few short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical, almost entire with occasional short spines. *Florets* deep yellow in the mature bud, yellow when open, fading to red.

Type 20. Very early, height 98 cm., somewhat spreading. *Leaves* 14 × 4 cm., oblanceolate, serrate, very light green. *Inflorescence leaves* lanceolate, spinose-serrate with numerous spines. Outer *involucral bracts* leafy, constricted above the base, linear lanceolate, spinose-serrate with numerous spines ; inner bracts narrower, smooth. *Florets* deep yellow in the mature bud, yellow when open, fading to red.

Type 21. Late, height 128 cm., habit spreading. *Leaves* 20 × 6 cm., oblanceolate, incised, somewhat light green. *Inflorescence leaves* lanceolate, spinose-serrate with numerous short spines. Outer *involucral bracts* leafy, constricted above the base, lanceolate, spinose-serrate with numerous spines ; inner bracts narrower, smooth. *Florets* deep yellow in the mature bud with a red spot on the apex, yellow without the red spot when open, fading to red.

Type 22. Early, height 131 cm., habit somewhat erect. *Leaves* 19 × 6 cm., oblanceolate, incised, dark green. *Inflorescence leaves* lanceolate, spinose-serrate with numerous short spines. Outer *involucral bracts* leafy, constricted above the base, obovate to rounded, spinose, inner bracts narrower, smooth. *Florets* deep yellow with a red spot on the apex in the mature bud, yellow without the red spot when open, fading to red.

Type 23. Intermediate as regards time of maturity, height 105 cm., habit spreading. *Leaves* 19 × 6 cm., oblanceolate, serrate, light green. *In-*

Types 1 8 2 6

DISTRIBUTION OF COLOUR

5 23 15 17

SAFFLOWER FLORETS.

florescence leaves lanceolate, spinose-serrate with short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical, spinose-serrate with a few short spines; inner bracts narrower, smooth. *Florets* deep yellow with a reddish base in the mature bud, yellow when open, fading to red.

Type 24. Late, height 156 cm., habit erect. *Leaves* 25 × 6 cm., oblanceolate, incised, somewhat light green. *Inflorescence leaves* lanceolate, nearly entire with a few short spines. Outer *involucral bracts* leafy, constricted above the base, elliptical with a few short spines; inner bracts narrower, smooth. *Florets* deep red with a yellow apical point in the mature bud, orange red when open, fading to a very deep red.

IV. ECONOMIC ASPECTS.

As safflower is cultivated either for the oil in the seeds or for the dye in the flowers or for both, it is interesting to compare the oil content and the colour of the faded florets in the types which have been isolated. The percentage of oil or rather the percentage of the seed extracted by ether has been determined in the Chemical Section at Pusa with the following results :—

TABLE VI.

Oil content of the types of Indian safflower.

Type	Date of appearance of first flower	Weight in grammes of 100 seeds	Percentage of oil	Colour of faded florets
1	2-3-14	6·1	13 86	Colourless
2	25-2-14	4·4	26·86	Light brown
3	16-2-14	5·6	24·12	Brown
4	14-2-14	3·9	25·60	Brown
5	23-2-14	4·5	27·26	Red
6	23-2-14	5·1	26 77	Reddish yellow
7	20-2-14	5·0	30·19	Reddish yellow
8	23-2-14	4·2	24·00	Light brown
9	23-2-14	4·8	27·99	Brown
10	3-3-14	4·2	25·54	Red
11	23-2-14	3·2	28·19	Red
12	20-2-14	5·1	27·18	Red
13	2-3-14	4·0	24·43	Red
14	25-2-14	3·8	27·19	Red
15	20-2-14	3·1	26·42	Red
16	27-2-14	3·9	25·72	Red
17	9-3-14	3·9	28·64	Deep red
18	2-3-14	4·2	24·99	Red
19	10-3-14	2·8	28·95	Red
20	23-2-14	4·3	26 53	Red
21	23-2-14	2·9	25·46	Red
22	20-2-14	5·3	20·77	Red
23	25-2-14	3·4	28·35	Deep red
24	4-3-14	3·1	26·82	Deep red

An examination of the table shows that there is no antagonism between high oil-content and the full development of the red colouring matter as indicated by the faded florets. Oil-yielding and colour-producing capacity appear to be independent of one another. Indeed, some of the types, such as 17 and 24 which are high in oil, also develop a deep red colour in the florets. This does not necessarily mean that these types will be the best yielders. Cropping power depends on other factors in addition to the percentage of oil and the development of the red colour. The habit of the plant, the development of the root system and the time of flowering and maturity influence yield to a very great extent.

In order to obtain a definite opinion on the range in colour content of representative types, samples of flowers were prepared in the country fashion and submitted to Dr. Marsden, Tinctorial Expert to the Government of Madras. The flowers were picked before fading and afterwards pounded in a mortar with a little water. The soluble yellow substance was squeezed out and the residue pressed into a cake. These cakes were kept covered for a night, broken up and dried in the sun the next day. Twelve samples were submitted to Dr. Marsden, three of which (types 1, 8 and 9) did not develop any red colour on fading. His report, dated May 3rd 1915, was as follows :—

" I am sending to-day, dyed hanks giving the comparative strengths of the samples of safflower forwarded to me.

The method of treatment was the same in each case, a weighed quantity of the flowers being taken and extracted with water slightly acidified with acetic acid until the yellow colouring matter was almost entirely removed. As the washing proceeded, the residual flowers became bright red coloured and when the washings were but faintly coloured the extraction was continued with a measured, dilute solution of carbonate of soda. The flowers were left a dull drab colour by this extraction and hanks of bleached cotton yarn were worked in the extracts and the dyeings finished by the addition of tartaric acid.

The shades are of the same tone in general, but No. 23 and Dacca are somewhat duller and bluer than the others.

With regard to intensity of shade, I would place them in the following order—Type Nos. 24, 17, Dacca, 20, 16, 23, 10, 12, 5.

Nos. 1, 8, 9, contain no red dye. I have no tintometer with which to measure the absolute depths of shade but I estimate that type 24 is about eight times as rich in dyestuff as type 5.

With regard to the value of the dyestuff this of course is a question of taste and market demand. The shade is delicate in tone, but it is also very

sensitive and is changed so readily by various influences (alkali, acid, light) that there can be no possibility of the dye finding any application in directions in which the market demands any degree of resistance to these influences. Its properties in this respect are so poor that it possessed no chance of competing with the first synthetic dyestuff placed on the market which approximated to it in shade and now there are many which surpass it in brilliance, fastness and general utility, so that I see no hope of it ever again coming into general use. The rhodamine dyes displaced it when they were first discovered, even though they were sold at 25 to 30 shillings a pound and their price now being down to between one and two shillings, it is hopeless to think of their use being given up when the tests show that 1 lb. of say rhodamine 6·G is equal in dyeing power to 100 lb. of safflower, and the manipulation is easier."

The report brings out quite clearly the great range in colour content in the types which it would appear can be judged roughly by eye after the yellow colouring matter has been extracted. In spite of the fugitive nature of the dye, it is interesting to find that it is still used in India and has not yet been entirely displaced by synthetic products.

The chief value of the crop at the present time is undoubtedly the oil in the seeds while the colour in the flowers is only a secondary matter. Where the crop is of sufficient importance, its improvement is a comparatively simple matter. Form separation is clearly indicated as the method to be followed and once the types have been separated from the heterozygotes and studied in pure culture, all that is necessary is to compare the yields of all the likely kinds. In such work, four main points have to be considered in selecting for yield—oil-content, time of maturity, habit and colour content. The types which branch and stand well, such as Nos. 5, 6, 7, 14, 15, 16 and 19 are likely to yield better than the tall types with crowded branches. The time of flowering and the period when ripening takes place are also important. While the improvement of safflower by selection is not likely to be difficult, it will not be an easy matter to establish a superior kind on a large scale. Once a stock of pure seed has been obtained, it will be necessary to replace the country crop entirely and to carry this out on a systematic plan starting from a given centre. If this is not accomplished, natural crossing will take place and little or no permanent improvement will result from distributing seed. The improvement of a crop in India, in which natural crossing is common, is largely a matter of organization and the isolation of a better kind can only be regarded as an important step in the work.

INDIAN MUSTARD (RAI).

I. INTRODUCTION.

Indian mustard (*Brassica juncea*, H. f. & T.) is fairly extensively cultivated in the Gangetic plain, particularly in Bengal and Bihar. In the United Provinces and the Punjab, mustard gives place to rape (*tori* or *toria*). According to Duthie and Fuller,[1] mustard is rarely grown alone in the United Provinces but is subordinate to wheat, barley and peas and is usually restricted to the borders of fields. Watt[2] states that mustard yields less oil than rape (one-fourth instead of one-third) to the weight of seed and that the oil is less esteemed as an article of food. The seed is very generally used in India as a spice to give flavour to vegetables and sometimes also as a medicine.

The area under this crop in India is not given separately in the *Agricultural Statistics of India* but is included with colza (*sarson*) and rape as "rape and mustard." The export of mustard, however, is given separately and, in 1912-13, amounted to 73,058 cwt.[3]

In 1909, a beginning was made at Pusa in the study of the oil seed crops of India belonging to the genus *Brassica*. For this purpose, 144 samples of seed of these crops, which had been collected from various parts of India, were sown at Pusa. In nearly all cases, the samples were mixtures of varying proportions of mustard, colza and rape. As it was not possible to deal simultaneously with all the forms of these three species which appeared in the cultures, type separation was limited to the mustard crop. Self-fertilized seed of three hundred and ninety-eight single plants of *rai* was obtained at the harvests of 1909 and 1910. Many of the plants, however, proved to be heterozygotes and most of these splitting cultures were rejected. In 1914, one hundred and two distinct types, which bred true, remained. These 102 pure lines, which are all quite distinct in the field, form the material on which our study

[1] Duthie and Fuller, *Field and Garden Crops of the North-Western Provinces and Oudh*, vol. II, 1883, p. 33.

[2] Watt, *Commercial Products of India*, 1908, p. 181.

[3] *Annual Statement of the Sea-borne Trade and Navigation of British India*, vol. I, 1913, p. 685.

of Indian mustard is based. As the original seed was collected from a wide area and as many as 398 single plants were originally selected in 1910, it is evident that the Pusa cultures can be taken to represent adequately the botanical constitution of this crop.

The botanical aspect of the various oil seeds of Bengal and Bihar, belonging to the genus *Brassica*, has been studied in detail by Prain[1] and the results naturally form the beginning of any further work on these crops. He sums up his account as follows :—

"As regards the relationship that our three staple mustard-oil crops bear to the corresponding crops in Europe, it may be tentatively held :—

(1) that *rai* (*Brassica juncea*) is a crop not grown in Europe, at any rate on a commercial scale, but that it takes the place here of *Brassica nigra* and *Brassica alba*, which in turn are not grown in India ;

(2) that *sarson* (*Brassica campestris* var. *sarson*) is a crop not grown largely, if at all, in Europe, but that in India it takes the place both of *Brassica compestris* var. *oleifera* and *Brassica Rapa* var. *oleifera*, which in turn are hardly ever met with here.

(3) that *tori* (*Brassica Napus* var. *dichotoma*) seems to be the same plant as *Brassica præcox* (summer rape) or if not the same is at least very like and very near it and is undoubtedly the plant that in India takes the place of *Brassica præcox* and of *Brassica Napus* var. *oleifera*."

Prain concludes that *rai* or Indian mustard is the most important of the three species of *Brassica* grown in Bengal and Bihar, and is met with everywhere "except in Chota Nagpur where it is practically unknown. It is easily recognised by having none of its leaves stem-clasping, and, after reaping, its seeds, which are brown, can be readily distinguished from those of *tori*, or Indian rape, by their smaller size, their being distinctly rugose, and being reddish brown all over. From *sarson*, which has white seeds or, less often in Bengal, brown seeds, it is equally easily distinguished ; *sarson* seeds are always considerably, often very much larger, and even when brown have the seed coats smooth.

There are three sub-races, a tall, late kind, and two shorter earlier kinds, one of these latter with bristly hairs, the other smooth with darker coloured stems."

[1] Prain, *The Agricultural Ledger*, vol. V, 1901, p 1

II. BIOLOGY OF THE FLOWER.

Flowering.

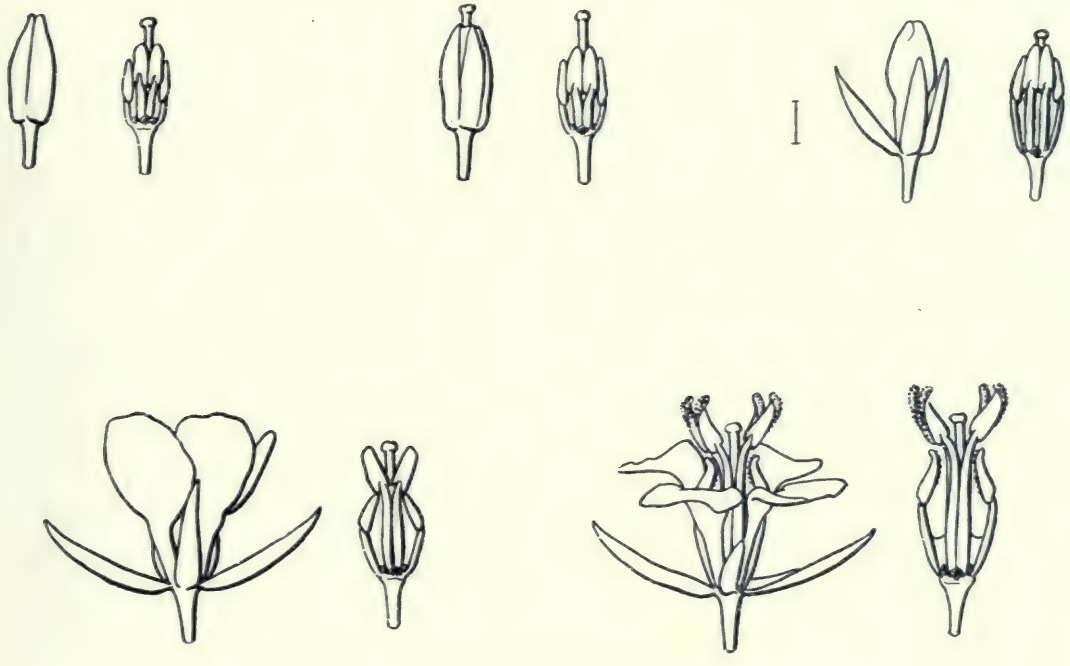
At first, the flowers form short corymbs about 2·5 cm. long when the lowest flower opens after which the inflorescence elongates into a raceme from 20 to 80 cm. in length. The flowers are borne on pedicels, each from 0·4 to 1·4 cm. long, which are without bracts or bracteoles. As the fruit ripens, the stalks slightly increase in length.

The total flowering period varies considerably according to the earliness or lateness of the type. The onset of the hot winds at once terminates the flowering of all late forms but does not affect the early kinds as these have ripened most of their seed before the hot weather begins. Observations, made in 1915 on 21 types, showed that the flowering period varied from 43 to 64 days. The earliest type commenced to flower on November 10th, 1914 and the latest on January 2nd, 1915.

The flowers of the racemes open in acropetal succession. As a rule, two to four flowers are open at once on each raceme and when the plants are in full bloom each may carry as many as ten open flowers at the same time. Most of the flowers begin to open from 9 A.M. to 12 noon, but some partly open up to 4 P.M. and a few before 9 A.M. They remain open for three days, fading gradually every day and on the fourth day the petals and sepals are shed.

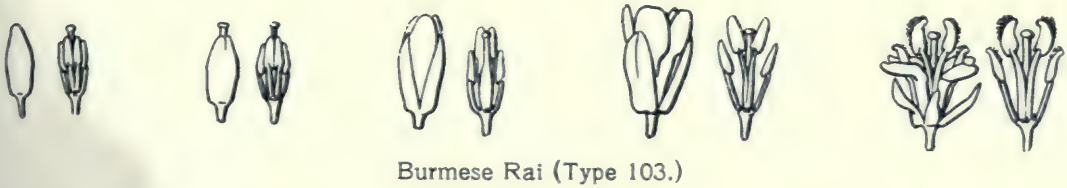
Pollination.

In the bud stage, the immature stamens are always below the stigma. Before the flower opens, the style often increases in length and the sepals and petals expand just sufficiently to produce a small opening at the apex through which the stigma is extruded into the air to a distance of 2 mm. As a rule, the extrusion of the stigma takes place in the evening, and all such flowers invariably open the next morning about 9 A.M. The length of style extruded varies a great deal even in the same plant but in many cases the stigma does not grow out into the air but remains flush with the opening of the tube formed by the corolla. Observations on December 18th, 1914 showed that out of 36 flowers which opened the next day, 18 showed extruded stigmas the previous evening. The stigmas are receptive as soon as they reach the outer air. Soon after the extrusion of the stigma, two other changes take place—the sepals begin to open and the corolla and stamens begin to grow. The increase in length of the corolla is so rapid that it soon grows past the stigma and this latter disappears again before the flower opens the next morning. Just before opening, the filaments have carried the anthers almost



Indian Rai (Type 60.)

Mohari.



Burmese Rai (Type 103.)

FLOWERING DETAILS IN RAI AND MOHARI.

up to the stigma (Plate III). Soon after the corolla opens, the filaments of the long stamens turn half round so that the pollen-covered surfaces of their burst anthers are turned towards the adjacent short stamens which have their pollen surfaces directed towards the style (Fig. 1.) At this period, the

Fig. 1. Pollination by bees.

nectar is secreted, particularly by the pair of nectaries on the inner side of the bases of the short stamens. Large bees in great numbers visit the flowers soon after they are open. These insects, in searching for honey, always deal with one side of the flower first and insert themselves between the burst long and short stamens. The short stamen touches the under side of the thorax while the long stamens touch the bee's head and the stigma at the same time. The bee then passes over the stigma to visit the nectary on the other side and again comes between the other set of burst anthers touching the stigma again with the pollen-covered thorax. These arrangements are obviously effective in promoting pollination and it is clear that a certain amount of crossing is to be expected. The small bees which visit the flowers for the nectar do not act in the above manner but take nectar from the side direct without passing over the stigma. All pollen-gathering bees, however, move over the stigma and so bring about pollination. In the absence of insect visitors, pollination is effected by the long stamens, the upper portion of the anthers of which bends towards the stigma so that any slight shaking of the flower by wind is sufficient to accomplish the transfer of pollen. This is confirmed by the fact that the flowers set normally under bag or under nets without any difficulty.

Natural cross-fertilization.

Large series of *rai* cultures have, on two occasions, been grown at Pusa primarily for the purpose of form separation. These cultures also afford evidence as to the occurrence of heterozygotes in the ordinary crop.

In 1909, 82 different single plants were sown. Of these, 55 bred true and 27 gave rise to mixed cultures. Seventeen plants split with regard to the close or open arrangement of the pods[1] while 10 split into tall and short plants.

In 1910, 316 additional single plants were selected from the produce of seed collected from many parts of India. In every case, the seed of these 316 plants was raised under bag so that no crossing took place at Pusa and any heterozygotes must have been produced in the districts. An examination of these cultures showed that 174 were mixed while 142, or nearly 45 per cent., bred true. An examination of the cultures, which were not uniform, showed that splitting took place in many directions such as hairy and smooth leaves, spreading and appressed pods, late and early ripening and tallness and shortness. Thus out of a total number of 398 single plant cultures grown at Pusa, no less than 197 or 49·5 per cent. bred true. These figures indicate that crossing is not so common in *rai* as would be expected judging only from the structure of the flower and from the method of pollination. It is clear that in a selection such as this, primarily intended for form separation in which every type is isolated, the results do not give any true idea of the proportion of natural crosses in the country crop. The method would favour the selection of heterozygotes as it includes every plant which appears a little different from the rest.

In 1915, the seed of five types, obtained from free-flowering plants growing side by side, was sown and the resulting cultures examined for heterozygotes. The results (Table VII) give a fair idea of the amount of crossing which takes place in any year when different types are grown in lines next to next and when no precautions are taken to exclude the visits of insects.

TABLE VII.

Crossing in rai at Pusa in 1914.

Type	Total number of plants	Number of heterozygotes	Percentage of crossing
7	307	23	7·5
17	235	20	8·5
83	241	45	18·7
91	71	24	33·8
226 D	213	39	18·3
Total	1,067	151	Average 14·1

These results show that in *rai* self-pollination is the rule and that cross-pollination takes place to some extent. A study of the country crop shows

[1] *Mem. Dept. Agr. in India (Botanical Series)*, vol. III, 1910, p. 318.

that while heterozygotes occur, a large proportion of the crop breeds true. When pure lines are grown next to next and allowed to cross, the Pusa results of 1915 show that about 15 per cent. of crossing takes place in any one year when a very large number of types are grown next to next in lines. In the field, the proportion of heterozygotes produced in any year would naturally be far fewer than 15 per cent. as the opportunities for crossing between different types would be much less. These results agree with the experience of von Rümker,[1] in the case of rape at Breslau, who states that in this crop self-fertilization is the rule while cross-fertilization is possible.

As would be expected from the predominance of self-fertilization in *rai*, the continued propagation of the types from seed obtained from protected flowers leads to no apparent loss of vigour. In 1914-15, a careful comparison was made between plants raised from bagged and unbagged seed in the case of four types. The cultures were grown next to next and no differences in size or in vigour of growth could be detected.

Hybridization.

All the various types of Indian mustard cross freely among each other and also with the forms isolated from Burma mustard mentioned on page 268. Some crosses between various types have been carried to the second generation when the following results were obtained.

(1) When tall and short types are crossed, the F_1 generation is in some cases taller than the tall parent, while in other cases it is intermediate, as will be seen in Table VIII in which the results of 1913-14 are shown.

Table VIII.

The inheritance of height in rai.

Parents	Height in feet	F_1	Height in feet
Parent—Type 4	5·5		
Parent—Burma 226 D	4·3	F_1 Type 4 × Burma 226 D	6
Parent—Type 4	5·5		
Parent—Burma 218	5·8	F_1 Type 4 × Burma 218	6·1
Parent—Type 39	5·5		
Parent—Burma 226 D	4·1	F_1 Type 39 × Burma 226 D	6·0
Parent—Type 39	5·4		
Parent—Burma 218	5·9	F_1 Type 39 × Burma 218	6·2
Parent—Type 102	8·9		
Parent—Burma 226 D	4·4	F_1 Type 102 × Burma 226 D	7·0
Parent—Type 102	9·5		
Parent—Burma 218	5·9	F_1 Type 102 × Burma 218	8·0

[1] *Zeit. f. Pflanzenzüchtung*, I, 327. 1913.

In the first four crosses the F_1 is taller than the taller parent while in the last two it is intermediate.

(2) When types with close and spreading pods are crossed, the progeny shows that the close arrangement is prevailing.

(3) When Indian mustards with divided leaves are crossed with the Burma forms with entire leaves, the F_1 is intermediate while a series is obtained in the F_2 (Plate IV).

(4) When late and early forms are crossed, the F_1 is intermediate.

III. FORM SEPARATION.

The forms of Indian *rai* so far studied agree with the following general description of the crop which has been adapted from Prain's account :

A cold weather crop in the plains of India of tall, annual, much-branched or spreading herbs from 90 to 285 cm. high and 45 to 110 cm. across. *Root* slender, tapering, 15 to 35 cm. long. *Leaves* large, the blades of the basal from 15 to 48 cm. long, 8 to 20 cm. wide, sinuate-lyrate, tapering to a stalk 2·5 to 8 cm. long, decreasing upwards ; upper leaves small, narrow, sessile, entire with a slight development of bloom on the under surface. *Stem* branching from the fourth or fifth leaf upwards, all branches about as long as the continued main stem and often again branching, usually more or less tinged with purple, especially near the joints. *Flowers* in short corymbs about 2·5 cm. long when the first flower opens, subsequently elongating into a raceme 20 to 80 cm. long with nearly equal slender pedicels 0·5 to 1·5 cm. long, without bracts or bracteoles, either spreading or appressed to the stem. *Sepals* slightly spreading, 0·5 to 0·75 cm. long, 0·1 to 0·15 cm. wide, green, turning yellowish before falling. *Corolla* 1·2 to 1·8 cm. across ; petals with a pale green narrow claw 0·25 to 0·35 cm. long and a bright yellow, spreading, regularly obovoid blade 0·6 to 0·8 cm. long, 0·5 to 0·75 cm. across. *Pods* 2-valved, flat, including the beak 3·5 to 5 cm. long, 0·3 to 0·5 cm. wide, beak narrowly conical 0·7 to 1·0 cm. long ; valves convex, rigid, thinly leathery, distinctly beaded opposite the seeds, with a straight strong midrib, prominent outside, with rather strong prominent looped veins on each half valve. *Seeds* about 10 under each valve, spherical, brown, finely rugose ; hilum the colour of the remainder of the testa ; cotyledons yellow.

The size to which *rai* attains in India depends among other factors on the soil temperature. At Pusa, in seasons when the *hathia* rains fail in October

RAI. 2. 52
X
RAI. 4. 226D

THE RANGE IN LEAF FORM IN THE SECOND GENERATION.

PLATE IV.

Type 1. Type 39. Type 103 (Burma.) Mohari.

THE POSITION OF THE PODS IN RAI AND MOHARI.

PLATE V.

and when sowing is carried out at the ordinary time in the warm soil, it is observed that the crop does not remain long in the vegetative condition but commences to shoot prematurely and to flower early. The yield of seed under such conditions is low. This abnormal development in such seasons can to some extent be prevented by cooling the soil by cultivation in October and by late sowing. Similar abnormal growth is seen in crops like yellow-flowered tobacco (*N. rustica*) and *sarson* if they are sown too early and before the ground has cooled sufficiently. One of the chief uses of the *hathia* rains in Bihar appears to be to cool the country low enough for the cold weather crops to thrive.

The 102 types of Indian mustard offer no great difficulty in classification provided this is based both on morphological and on field characters. Up to the division of the types into main groups, the classification follows the usual lines. The precise distinction between the types however can only be fully appreciated in the field when they are grown in lines, next to next, under uniform conditions. In this way, what may be called the massed habit comes into play and the small differences in the mode of branching, in the size and tone of colour of the leaves and in the time of ripening become added together and serve to distinguish the various forms. In herbarium specimens, these distinctions would be lost. The labour of reducing them to paper is so great that no effort has been made to accomplish this exceedingly difficult task. Before giving the actual classification, some reference is necessary to the most important characters on which it is based.

Position of the pods. In the majority of the types, the ripe pods stand at an angle of about 50° from the axis of the inflorescence and in these cases the pods can be described as spreading. In a few cases, however, and these do not seem to have been observed by Prain, the pedicels when ripe stand much closer to the axis at a general angle of from 5° to 10°. In these cases the pods are distinctly appressed. The position of the pods in the various types is very constant from year to year so that this character can be safely used in classification (Plate V).

Hairs on the leaves. In the seedling stage, all the types have some hairs on the first leaves but the range between the hairy forms and those which are nearly smooth is very great. As growth proceeds and the full sized leaves are developed, these differences increase and when the plants have attained their full development, the distinction between the hairy leaved and smooth leaved types is well-marked.

Mode of branching. The angle at which the secondary branches arise varies considerably between the various types and is a definite character. This expresses itself also in the breadth of the full-grown plant and, provided the land on which the types are grown is uniform and provided the measurements are all taken at the stage when the plants are fully grown, the breadth measurements would express the general mode of branching. After the seeds begin to form, the plants bend over with the weight of the developing pods and this character then becomes less easily observed.

Height. The height to which the types attain is very constant from year to year and this character is therefore of great use in the classification. It can most easily be measured by uprooting the ripe plants and measuring them with the roots upward. Height is generally correlated with time of flowering. The tall plants are always late while the dwarf types are always early.

Growth period. The length of time between sowing and ripening is difficult to determine in Bihar as the onset of the hot weather is often so rapid that all late plants are dried up and normal ripening is then impossible. An accurate indication of the growth period is obtained, however, by the determination of the time when the first flower opens. This is earliest in the case of the rapidly maturing types and progressively later for the tall later kinds.

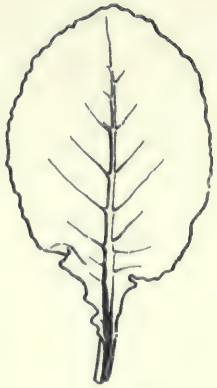
Leaf characters. The types differ considerably among themselves in details relating to the size, colour, and degree of division of the leaves. These differences come out in the massed habit and help to distinguish the types in the field, but they almost defy description and could only be adequately dealt with by actual drawings or photographs (Plate VI.).

The various types of *rai* which have been studied can be classified as follows :—

I. Pods appressed to the stem.
   1. Upper leaves distinctly hairy.
      Types 1 to 6.
   2. Upper leaves smooth or nearly so.
      Types 7 to 16.

II. Pods spreading.
   1. Upper leaves distinctly hairy.
      Types 17 to 69.
   2. Upper leaves smooth or nearly so.
      Types 70 to 102.

109 (Burma.)



103 (Burma.)

72.

17.

102.

106 (Burma.)

16.

83.

1

THE RANGE IN LEAF FORM IN RAI.

PLATE VI.

The details relating to the place of origin, the vernacular or other name of the mixtures from which the types were isolated, the height and the time of flowering are given in the tables below. In cases where the type occurred as a stray plant in a mixture this fact is indicated.

Pods appressed to the stem ; upper leaves distinctly hairy.

Type	Place of origin	Vernacular name	Height in feet in 1914	Time of flowering
1	Bhagalpur	*Rai Benari* (stray)	3·75	Early
2	Maidapur (Darbhanga)	*Rai* (stray)	4·5	,,
3	Pusa	,,	5·75	,,
4	,,	,,	6	,,
5	,,	,,	5·75	,,
6	,,	,,	4·75	Intermediate

Pods appressed to the stem ; upper leaves smooth or nearly so.

7	Pusa	*Sarson* (stray)	3·75	Early
8	,,	*Rai*	4·5	,,
9	Shankarpur	,,	5·5	,,
10	,,	,,	4·5	,,
11	,,	,,	5	,,
12	,,	,,	5·25	,,
13	Pusa	,,	4·5	,,
14	,,	,,	5	,,
15	,,	,,	3·5	Intermediate
16	,,	,,	5·5	,,

Pods spreading ; upper leaves smooth or nearly so.

17	Maidapur (Darbhanga)	*Rai*	3·5	Very early
18	,,	,,	3·75	,,
19	Dacca	Black *sarson*	3·5	,,
20	Patna	*Sarisha*	4·25	,,
21	Ranchi	*Latni*	3·75	,,
22	Pusa	*Rai*	5·25	,,
23	Semaria Ghat	*Rainchi*	4·75	,,
24	Patna	*Rai*	4·25	,,
25	Semaria Ghat	*Rainchi*	4·5	,,

Pods spreading; upper leaves smooth or nearly so.

Type	Place of origin	Vernacular name	Height in feet in 1914	Time of flowering
26	Allahabad	*Lahi*	3·75	Very early
27	,,	*Sarson*	4·5	Early
28	Sultanpur	*Rai*	4·5	,,
29	,,	,,	5·5	,,
30	Benares	,,	5·75	,,
31	Hamirpur	*Lahi*	6·5	,,
32	Fatehpur	,,	6	,,
33	Maidapur (Darbhanga)	*Rai*	5·75	,,
34	Shahabad	*Lalka tori*	6	,,
35	Dumraon	Jubbulpur mustard	5·75	Intermediate
36	Pusa	*Rai*	5·5	,,
37	,,	,,	6	,,
38	,,	,,	5	,,
39	Bhagalpur	*Rai Benari*	5·25	,,
40	Dumraon	Jubbulpur mustard	7	,,
41	Kheri	*Lahi*	4·75	,,
42	Fatehgarh	,,	6·75	,,
43	,,	,,	5·75	,,
44	Pusa	*Rai*	6	Late
45	,,	,,	7·25	,,
46	,,	,,	6·5	,,
47	,,	,,	6·75	,,
48	,,	,,	6·25	,,
49	Sultanpur	,,	6	,,
50	Agra	*Lahi*	6·25	,,
51	Hyderabad	*Rai*	6·75	,,
52	Mirpur-khas	Rape	8	,,
53	Dumraon	Raipur mustard	7·25	,,
54	,,	Jubbulpur mustard	8·25	,,
55	Fatehgarh	*Lahi*	7	,,
56	Hamirpur	,,	7·25	,,
57	Delhi	Black *sarson* (stray)		,,

Pods spreading ; upper leaves smooth or nearly so.

Type	Place of origin	Vernacular name	Height in feet in 1914	Time of flowering
58	Shahabad	*Lalka tori*	7·25	Late
59	Dacca	Indian rape	7·35	,,
60	Meerut	Black *sarson*	6·5	,,
61	Mirpur-khas	Mustard	6·5	,,
62	,,	,,	7·5	,,
63	Dumraon	Raipur mustard	7	,,
64	Aligarh	*Lahi*	6	,,
65	Hoshangabad	*Rai*	6	,,
66	Ahmednagar	*Mohari*	7·75	,,
67	Meerut	*Kali sarson*	7·5	,,
68	Aligarh	*Lahi*	8	,,
69	,,	*Kali sarson*	7	,,

Pods spreading ; upper leaves distinctly hairy.

70	Ranchi	*Taramira* (stray)	2·5	Very early
71	,,	,, ,,	2·75	,,
72	Hooghly	*Lahi*	3·75	,,
73	Ballia	,,	3·5	,,
74	Pusa	*Rai*	3·75	,,
75	Basti	,,	4·25	,,
76	Allahabad	Red *sarson*	4	,,
77	Pusa	*Rai*	4·5	Early
78	,,	,,	4·5	,,
79	,,	,,	4·75	,,
80	,,	,,	4·25	,,
81	,,	,,	5·25	,,
82	,,	,,	4·5	,,
83	Kheri	*Lahi*	5	,,
84	Pusa	*Rai*	4·75	,,
85	Patna	,,	5	Intermediate
86	Benares	,,	5·5	,,
87	Fatehpur	*Lahi*	5·25	,,

Pods spreading ; upper leaves distinctly hairy.

Type	Place of origin	Vernacular name	Height in feet in 1914	Time of flowering
88	Maidapur (Darbhanga)	*Rai*	5·75	Intermediate
89	Delhi	Black *sarson* (stray)	7	,,
90	Fatehgarh	*Lahi*	5·75	,,
91	Allahabad	*Sarson*	6	,,
92	Bhagalpur	*Rai Benari*	6	,,
93	Pusa	*Tori* (stray)	5·75	Late
94	,,	*Rai*	6	,,
95	,,	,,	6·25	,,
96	Kheri	*Lahi*	6·25	,,
97	Ahmednagar	*Mohari*	7	,,
98	Aligarh	*Kali sarson*	7	,,
99	Dumraon	Jubbulpur mustard	6	,,
100	North Arcot	Mustard	6·25	,,
101	,, ,,	,,	7	,,
102	,, ,,	,,	9·5	,,

Burma Mustard.

In a single sample of seed from Burma, described as mustard, a good many single plant selections were made, all of which gave mixed offspring. As these however set seed readily under bag, thirteen cultures breeding true (Types 103 to 115) were obtained in 1914. These cultures exhibit a great range as regards leaf form. In some, the lower leaves are entire, while in others, they are much divided and do not resemble any ordinary Indian forms of *rai*, *tori*, or *sarson*. The leaves also have a slight amount of bloom and a few hairs.

These Burmese forms cross readily with the various types of Indian mustard. In one case, where a very deeply divided Burmese type was crossed with type 60, the leaves in the F_1 were intermediate while, in the F_2, a great range was obtained which is represented in Plate IV.

The occurrence of these Burmese forms, with their curiously divided leaves, suggests the existence of oil seeds related to Indian *rai* which so far have not been described. The forms occurring in Burma are probably related to the oil-seeds of China.

Mohari.

While the work of form-separation in *rai* was in progress, a number of cultures of a somewhat similar plant were studied. These were obtained from seed described as *mohari*, from several places in Bombay, and as *asl rai* and *Multani rai* from Delhi and Amritsar. The seed is smaller and more pungent than that of *rai* and is said to be used in many parts of India for pickling purposes under the name of *asl rai*.

The plant appears to be an early form of *Brassica nigra*, Koch. The flowers of *mohari* are self-sterile so that the crop consists of a mass of heterozygotes in which form separation is impossible.

So far, all attempts to raise seed by crossing *mohari* with *rai* pollen and *rai* with *mohari* pollen have failed.

IV. SOME ECONOMIC ASPECTS.

In the present state of our knowledge of the mustard crop in India, it is clear that the only line of improvement worth striving for lies in the increase of the yield of seed. Questions of quality do not seem to arise and there are no indications in the literature which would lead one to suppose that any one form of *rai* is better than another either for local consumption or for the export trade.

The numerous types of *rai*, isolated at Pusa, differ very greatly from one another, both in time of ripening, in size, and in yielding power. There is every gradation between the dwarf, early-maturing forms and the taller robust kinds, characterized by greater yielding power. This great variety of form, obviously suited to a wide range of conditions, indicates that methods of form-separation or selection are the most likely to yield results of value in the work of improving the crop. Nothing would appear to be gained by hybridization until the great possibilities in selection have been completely exhausted. In this respect, *rai* is no exception to the rule. In the case of practically every crop in India, a botanical survey of the existing forms, accompanied by suitable methods of form-separation, should always precede any hybridization work. It is only where selection has failed to yield the desired improvement and where a type has to be synthesized for a particular purpose that hybridization becomes essential. In *rai*, a certain amount of natural crossing is constantly taking place in the field between the various forms leading to fresh combinations of factors. If, therefore, the selection work is

carried out on a sufficiently broad basis, the new types produced are almost certain to be secured in the process of form-separation.

As the flowering period in *rai* is somewhat short, the question naturally arises whether a single pure line, however excellent, is better in the long run than a judicious artificial mixture of types, the combined flowering period of which is longer than that of the pure line. Besides the insurance against the weather afforded by extending the flowering period, a mixture of types would appear to have two other advantages. Crossing would take place between the forms leading, in many cases, to increased size and vigour. In addition, a mixture of forms of slightly different habit might fill up the available space, both as regards the range of the root system and as regards the above ground portion of the crop, to greater advantage than a pure line. This is a matter for further experiment but it is obviously one which should be kept in mind particularly in those Indian crops where no question of quality is involved and where yield is the chief consideration.

The seed supply in improved crops like *rai*, where the seed is not particularly valuable, and where natural crossing takes place is a matter of some importance to an Agricultural Department. Each plant sets a relatively small quantity of seed and it is impossible in practice, on account of cost, to protect the seed crop on the large scale from foreign pollen. Total replacement of the existing crop in any area by an improved kind or by an improved mixture is obviously the only line of progress. For this to be effective, it is clear that there must be a central farm, producing a large bulk of seed every year, together with an efficient agency, working among the people, with this farm as a centre. In the absence of these arrangements, no real economic results are likely and it is questionable whether the preliminary work of improvement, in such crops as Indian mustard, is worth while unless the means of pushing the work to its natural conclusion in the villages are certain to be available.

In the case of *rai*, the replacement of the country crop by a superior variety will have to contend with difficulties apart from the question of central seed farms and an efficient organization in the Districts. These difficulties are concerned with self-sown seed and with the fact that the seeds of *rai* remain for a long time in the ground in a viable condition and germinate, a few at a time, every year. The land becomes self-sown with *rai*, not only on account of the splitting of the pods at harvest time, but also on account of the shedding of whole fruits in the case of these types where the pods are

closely appressed to the stem (Fig. 2). There is a very good example in the Botanical area at Pusa of land self-sown with *rai*. Four years ago, a plot of

Fig. 2. Shedding of pods in *rai* (Type 1).

wheat with weak straw was sown with *rai* to ascertain whether the standing power of the wheat would be improved. At harvest time, a certain amount of the *rai* seed was shed. These seeds are brought near the surface again at sowing time in cultivation and every year a considerable number germinate in October and have to be removed. After four years, the number shows no diminution. In areas which grow a good deal of *rai*, similar self-seeding is almost certain to be taking place continually. If, therefore, an attempt is made to replace the *rai* crop by a better type in such areas, it will be

impossible to keep the new kind pure even if the country crop is replaced systematically by pure seed from a central farm. The new variety will be immediately contaminated by the self-sown seed of the original crop and complete replacement would be the work of years.

Variety trials in *rai* on a field scale are not easy and are only possible at a well-equipped station. The contamination of the cultures through vicinism is bound to take place and seed raised from such plots cannot be used again with safety. Such trials therefore involve the production of self-fertilized seed in large quantities. Shedding of seed readily takes place at harvest so that reaping has to be carried out just before the plots are ripe. This involves the keeping separate and the safe storage of the different plots for some days during the drying process, a matter of some difficulty in the case of a bulky crop like *rai*.

QUETTA,
June 23, 1915.